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THE EFFECT OF ANTHROPOGENIC EMISSIONS ON THE RECENT RISE IN GLOBAL TEMPERATURE ANOMALIES

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ABSTRACT

Climate change is one of the most important issues currently facing mankind. One of the most important questions is determining the extent of climate change as well as the extent to which human activities cause climate change. Determining the answer to this question has important ramifications in shaping policy decisions to curb carbon emissions. The goal of this paper is to establish a relationship between the net human contribution to atmospheric carbon dioxide and the global temperature anomaly. To do this, we first form a climate model describing the relations between carbon dioxide concentration in the atmosphere and the temperature anomaly. Then we examine the components of the global carbon budget and form an expression for the human contribution to atmospheric carbon dioxide. In our results section, we use data from various databases to confirm the relation between carbon dioxide concentration and temperature anomalies; compare the projected gain in atmospheric carbon dioxide and the actual growth and construct a relation between the net human contribution to atmospheric carbon dioxide and temperature anomalies. We observe that there exists a strong correlation between the human contribution and the increasing temperature anomalies which is logarithmic in nature. Finally, we elaborate on any errors or uncertainties in our data.

KEYWORDS: Anthropogenic, Global Temperature & Anomalies

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Original Article

INTRODUCTION

The purpose of this paper is to confirm a correlation between the increase in global temperatures to anthropogenic emissions. For this, we do not use global mean temperatures as actual temperature measurements are difficult to gather from all places over the globe. Instead, we use global temperature anomalies which refers to the departure of global temperatures from a reference value. We prefer to use temperature anomalies over mean temperatures as they are easier to measure and produce a greater accuracy over a larger area. We also cannot directly human emissionsas there exist both land and ocean sinks which absorb carbon dioxide and whose values vary with time. As not all human emission are absorbed by the atmosphere, we shall be evaluating the net anthropogenic contribution to atmospheric carbon dioxide i.e. the amount of human emissions which are released into the atmosphere after being absorbed by ocean and land sinks. Hence my research question is

"How does the global temperature anomaly vary with the net anthropogenic contribution to atmospheric carbon dioxide?".

In order to answer this question, we must divide it into two parts (1) What is the relation between carbon dioxide concentration in the atmosphere and temperature anomaly? (2) How much of the growth in atmospheric carbon dioxide can be attributed to human activities? In order to answer these questions, we must develop a climate model as well as a carbon budget and then compare data using existing databases to see whether the data matches

with the model developed.

THEORY

One of the reasons why carbon dioxide plays a unique role in the increase in global temperatures is due to its unique structure and spectroscopy. A gas molecule absorbs radiation of a particular wavelength only if the energy absorbed can be used to increase the internal energy of the molecule. This is achieved through a transition from a lower to higher state. Since these states within a molecule are discrete, molecules can only absorb radiations of certain wavelengths. These transitions could either be electronic, which require high energy radiations from the ultraviolet spectrum, or vibrational, which require low energy radiations from the far-infrared spectrum. Some absorption can also take place due to rotational transitions in the near-infrared spectrum[1].

The vibrational state of a CO_2 molecule is defined by a combination of three normal vibrational modes and by a quantized energy level within each mode. Vibrational transitions involve changes in the energy level (vibrational amplitude) of one of the normal modes. In the "symmetric stretch" mode the CO_2 molecule has no dipole moment, since the distribution of charges is perfectly symmetric; transition to a higher energy level of that mode does not change the dipole moment of the molecule and is therefore forbidden. Changes in energy levels for the two other, asymmetric, modes change the dipole moment of the molecule and are therefore allowed. In this manner, CO_2 has absorption lines in the near-IR. Contrast the case of N_2 . The N_2 molecule has a uniform distribution of charge and its only vibrational mode is the symmetric stretch. Transitions within this mode are forbidden, and as a result, the N_2 molecule does not absorb in the near-IR.

More generally, molecules that can acquire a charge asymmetry by stretching or flexing (CO_2, H_2O, N_2O, O_3, hydrocarbons...) are greenhouse gases; molecules that cannot acquire charge asymmetry by flexing or stretching (N2, O2, H2) are not greenhouse gases. Atomic gases such as the noble gases have no dipole moment and hence no greenhouse properties. Examining the composition of the Earth's atmosphere, we see that the principal constituents of the atmosphere (N_2, O_2, Ar) are not greenhouse gases. Most other constituents, found in trace quantities in the atmosphere, are greenhouse gases. The important greenhouse gases are those present at concentrations sufficiently high to absorb a significant fraction of the radiation emitted by the Earth; the list includes CO_2, H_2O, N_2O, O_3 and chlorofluorocarbons (CFCs). By far the most important greenhouse gas is water vapor because of its abundance and its extensive IR absorption features.

By plotting the efficiency of absorption of radiation by the atmosphere we can see that, the atmosphere is nearly 100% opaque in the UV spectrum due to electronic transitions in O2 and O3 and nearly transparent to the visible spectrum. The efficiency once again increases to 100% at IR wavelengths due to greenhouse gases. Therefore, we can conclude that greenhouse gases play a significant role in the warming of the atmosphere as most of the absorption by the atmosphere is by greenhouse gases.

We must now model the atmosphere taking into account the heating caused due to the greenhouse effect for which we need to make a few assumptions about the structure and behaviour of the atmosphere. We neglect any absorption in the visible spectrum by the atmosphere. We also assume thermodynamic equilibrium which means that alocalised atmospheric volume below 40kms is considered to be isotropic (emissions are non-directional) with uniform temperature.We define the effective emission temperature to be the temperature of the Earth in the absence of an atmosphere, only taking into account

[1] Jacob, Daniel. *Introduction to Atmospheric Chemistry*. Illustrated, Princeton University Press, 1999.

its reflectivity and its distance from the Sun. As the rate of absorption and emission are the same we can equate the solar insolation and the heat radiated by the Earth (calculated using the Stefan-Boltzmann law by assuming the Earth to be a black-body at T_e). This gives us[2]-

$$S\pi r^2(1-\alpha) = 4\pi r^2 \sigma T_e^4$$

Where S stands for the solar constant (the amount of solar radiation received per unit area), and α stands for the albedo of the Earth. The flux density emitted is defined as-

$$F = \sigma T^4$$

$$F = \frac{S(1-\alpha)}{4}$$

The relationship between surface temperature T_s, effective emission temperature T_e and vertical optical depth τ_g as given by Chamberlain[2] is:

$$T_s^4 = T_e^4\left(1+\frac{3\tau_g}{4}\right)$$

$$T_s^4 = \frac{F_e}{\sigma}\left(1+\frac{3\tau_g}{4}\right)$$

$$T_s^4 = \frac{(1-\alpha)S}{4\sigma}\left(1+\frac{3\tau_g}{4}\right)$$

Using the given expression for surface temperature, we can now calculate the heat flux from the ground to atmosphere or $F_{g\to a}$ by considering the surface to be a blackbody emitting radiation at T_s.

$$F_{g\to a} = \sigma T_s^4$$

$$F_{g\to a} = \frac{(1-\alpha)S}{4}\left(1+\frac{3\tau}{4}\right)$$

Differentiating the equation with respect to τ_g gives us:

$$\frac{dF_{g\to a}}{d\tau} = \frac{3(1-\alpha)S}{16}$$

Or,

$$\Delta F_{g\to a} = \frac{3(1-\alpha)S}{16}\Delta\tau$$

The value of τ varies with CO_2 concentration by the following formula taken from Lenton et al[3]:

$$\tau_{CO_2} = 1.73(CO_2)^{0.263}$$

Where CO_2 concentration is expressed in ppm$\times 10^{-6}$. If CO_2 concentration is expressed in ppm, then:

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[2]Chamberlain, Joseph, and Donald Hunten. *Theory of Planetary Atmospheres, Volume 36, Second Edition: An Introduction to Their Physics and Chemistry (International Geophysics)*. 2nd ed., Academic Press, 1989

[3]LENTON, TIMOTHY M. "Land and Ocean Carbon Cycle Feedback Effects on Global Warming in a Simple Earth System Model." *Tellus B*, vol. 52, no. 5, 2000, pp. 1159–88. *Crossref*, doi:10.1034/j.1600-0889.2000.01104.x.

$$\tau_{CO_2} = 0.457(CO_2)^{0.263}$$

More generally, we express the equation in the form:

$$\tau = aC^b$$

Let us assume that we wish to measure temperature anomalies in the atmosphere at a time t_0, where the optical depth was τ_0 and the CO_2 concentration was C_0. This gives us our initial conditions:

$$\tau_0 = a(C_0)^b$$

Diving equation u by equation v:

$$\frac{\tau}{\tau_0} = \left(\frac{C}{C_0}\right)^b$$

$$\frac{\Delta\tau + \tau_0}{\tau_0} = \left(\frac{C}{C_0}\right)^b$$

$$\Delta\tau = \tau_0\left(\left(\frac{C}{C_0}\right)^b - 1\right)$$

$$\Delta\tau = \tau_0\left(e^{b\,ln\frac{C}{C_0}} - 1\right)$$

Substituting the value of $\Delta\tau$ in our relationship between ΔF and $\Delta\tau$ gives us:

$$\Delta F_{g\rightarrow a} = \frac{3(1-\alpha)S\tau_0}{16}\left(e^{b\,ln\frac{C}{C_0}} - 1\right)$$

As we are concerned with the increase in surface temperatures, we shall look at the flux from the atmosphere to the ground and its corresponding radiative forcing. We denote the fraction of heat that is returned from the atmosphere to the surface as f_a. Therefore we can write $F_{a\rightarrow g}$ as:

$$\Delta F_{a\rightarrow g} = f_a \Delta F_{g\rightarrow a}$$

$$\Delta F_{a\rightarrow g} = f_a \frac{3(1-\alpha)S\tau_0}{16}\left(e^{b\,ln\frac{C}{C_0}} - 1\right)$$

Using the approximation $e^x = 1 + x$ for $|x| < 1$, and taking $\mathrm{x} = \mathrm{b}\ln\frac{C}{C_0}$ we get:

$$\Delta F_{a\rightarrow g} = f_a \frac{3(1-\alpha)S\tau_0 b}{16}\ln\frac{\mathrm{C}}{\mathrm{C_0}}$$

To simplify the above expression, we write it as:

$$\Delta F_{a\rightarrow g} = \beta\,ln\frac{C}{C_0} \tag{1}$$

Where $\beta = f_a\frac{3(1-\alpha)S\tau_0 b}{16}$. As per Mhyre et al[4] the value of β is approximately 5.35.In a simple global energy

[4] Myhre, Gunnar, et al. "New Estimates of Radiative Forcing Due to Well Mixed Greenhouse Gases." *Geophysical Research Letters*, vol. 25, no. 14, 1998, pp. 2715–18. *Crossref*, doi:10.1029/98gl01908.

balance model, the difference between these (positive) radiative perturbations and the increased outgoing long-wave radiation that is assumed to be proportional to the surface warming ΔT leads to an increased heat flux, ΔQ given by the equation[5]:

$$\Delta Q = \Delta F - \lambda\Delta T$$

Heat is taken up by the oceans which increases ocean temperatures.For a constant forcing, the system usually approaches a new equilibrium where the heat uptake $\Delta Q$is zero and the radiative forcing is fully countered by increased the outgoing long wave radiation. Therefore at this point, we can claim that,

$$\Delta F = \lambda\Delta T \qquad (2)$$

Where λ is defined as the climate feedback parameter and its reciprocal$S' = \frac{\Delta T}{\Delta F}$, is the climate sensitivity parameter.

FEEDBACK MECHANISMS

In addition to the radiative forcing produced due to the rise in carbon dioxide concentration, additional feedback loops are generated in response to the perturbations. This is because other parameters in the atmosphere (particularly water vapour and ice) change contributes to the cycle. These feedback loops can have an amplifying or damping effect on the sensitivity parameter. We define a net feedback parameter f as[6]:

$$\mathrm{f} = \frac{\Delta T_0}{\Delta T_{eq}}$$

HereΔT_{eq} as the change in the equilibrium change of global mean surface temperature and ΔT_0refers to the change in surface temperature required to restore radiative equilibriumif no feedback took place. We also know that:

$$\Delta T_{eq} = \Delta T_0 + \Delta T_{feedback}$$

Where $\Delta T_{feedback}$ is the additional temperature change resulting from feedback loops. The system gain g is defined as:

$$g = \frac{\Delta T_{feedback}}{\Delta T_{eq}}$$

From this relation it follows that:

$$g = \frac{\Delta T_{eq} - \Delta T_0}{\Delta T_{eq}}$$

$$g = 1 - \frac{1}{f}$$

Since there exist several feedback mechanisms we express $\Delta T_{feedback}$ as the sum of each individual

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[5] Knutti, Reto, and Gabriele C. Hegerl. “The Equilibrium Sensitivity of the Earth’s Temperature to Radiation Changes.” *Nature Geoscience*, vol. 1, no. 11, 2008, pp. 735–43. *Crossref*, doi:10.1038/ngeo337.

[6]Hansen, J., et al. "Climate sensitivity: Analysis of feedback mechanisms." *feedback* 1 (1984): 1-3.

feedbacksT_i i.e $\Delta T_{feedback} = \Sigma T_i$. Hence the gain is also expressed as sum of each individual gain.

$$g = \Sigma g_i$$

However the same cannot be said about the feedback factors. For example if

$$g = g_1 + g_2$$

$$f = \frac{f_1 f_2}{f_1 + f_2 - f_1 f_2}$$

One consequence of this nature of feedbacks is that if there is a relatively large feedback and a moderate or small feedback, the resulting net feedback would be drastically increased.

Returning to Equation 2 and substituting expression for F from Equation 1 in it we have:

$$S' = \frac{\Delta T}{\Delta F}$$

$$\Delta T = S' \beta \, ln \frac{C}{C_0}$$

Let $C = 2C_0$. The corresponding ΔT is denoted as S which is theequilibrium climate sensitivity. It is the equilibrium global average temperature change for a doubling of carbon dioxide concentrations[5].

$$\mathrm{S} = S' \beta \ln 2 \tag{3}$$

Therefore can write the equation for global temperature anomaly more simply as

$$\Delta T = \frac{S}{ln\,2} ln \frac{C}{C_0} \tag{4}$$

The ΔT in this equation refers to the change in temperature considering the feedback response i.e.ΔT_{eq}. Using this we can express S as:

$$\mathrm{S} = \mathrm{f} \Delta T_{0\,(2 \times CO_2)}$$

$$\mathrm{S} = \frac{1}{1-g} \Delta T_{0\,(2 \times CO_2)}$$

Here $\Delta T_{0\,(2 \times CO_2)}$ is the increase in surface temperature on doubling of carbon dioxide while neglecting feedback. Its value is about 1.2 K.

The equilibrium climate sensitivity$S$ factor is difficult to ascertain. This is primarily due to uncertainties in determining the extent to which feedback mechanisms impact temperature. Various climate models produce varying results for the value of S. constraints from observed recent climate change support the overall assessment that climate sensitivity is very likely (more than 90% probability) to be larger than 1.5 °C and likely (more than 66% probability) to be between 2 and 4.5 °C, with a most likely value of about 3 °C. More recent studies support these conclusions[7].

Global Carbon Budget

[7]Tomassini, Lorenzo, et al. “Robust Bayesian Uncertainty Analysis of Climate System Properties Using Markov Chain Monte Carlo Methods.” *Journal of Climate*, vol. 20, no. 7, 2007, pp. 1239–54. *Crossref*, doi:10.1175/jcli4064.1.

In order to assess the contribution of human emissions to the increase in temperature anomalies we must understand the nature of the carbon dioxide cycle, the balance that existed prior to the industrial revolution and the global carbon budget for anthropogenic emissions

The components for the global carbon budget include the following[8]

- Emissions from fossil fuel combustion and oxidation from all energy and industrial processes including that emitted from cement manufacturing (E_{FOS}). This figure includesinclude the combustion of fossil fuels through a wide range of activities (e.g. transport, heating and cooling, industry, fossil industry own use, and natural gas flaring), the production of cement, and other process emissions (e.g. the production of chemicals and fertilizers) as well as CO_2 uptake during the cement carbonation process.
- Emissions from deliberate human activities on land including those leading to land use change(E_{LUC}).This figure includes CO_2 fluxes from deforestation, afforestation, logging and forest degradation (including harvest activity), shifting cultivation (cycle of cutting forest for agriculture, then abandoning), and regrowth of forests following wood harvest or abandonment of agriculture. Emissions from peat burning and drainage are added from external data sets. Only some land-management activities are included in our land-use change emissions estimates. Some of these activities lead to emissions of CO_2 to the atmosphere, while others lead to CO_2 sinks. $E_{LUC}$is the net sum of emissions and removals due to all anthropogenic activities considered.
- The growth rate of atmospheric carbon dioxide expressed in Gt/yr(G_{ATM}).
- The sink of carbon dioxide on the ocean(S_{OCEAN}).
- The sink of carbon dioxide on the land(S_{LAND}). The sink action is brought about by the combined effects of fertilization by rising atmospheric CO_2 and N inputs on plant growth, as well as the effects of climate change such as the lengthening of the growing season in northern temperate and boreal areas. S_{LAND} does not include land sinks directly resulting from land use and land-use change (e.g. regrowth of vegetation) as these are part of the land-use flux (E_{LUC}), although system boundaries make it difficult to attribute CO_2 fluxes on land exactly between S_{LAND} and E_{LUC}

We would expect that the total sink in the land and the ocean and the gain in atmospheric carbon dioxide would equal the amount emitted from fossil fuels and human activities on land.In other words we would expect that,

$$E_{FOS} + E_{LUC} = G_{ATM} + S_{OCEAN} + S_{LAND}$$

We now express the projected growth in atmospheric growth as:

$$G_{ATM} = (E_{FOS} + E_{LUC}) - (S_{OCEAN} + S_{LAND}) \tag{5}$$

If anthropogenic activity is a major cause for climate change we would expect the actual annual growth in carbon dioxide to have a strong correlation with our projected values as we take natural sources to be negligible. We also have an expression for total human contribution as:

[8] Friedlingstein, Pierre, et al. "Global Carbon Budget 2020." *Earth System Science Data*, vol. 12, no. 4, 2020, pp. 3269–340. *Crossref*, doi:10.5194/essd-12-3269-2020.

$$C_{human} = \sum_{i=0}^{n} G_{ATM_i}$$

Database Authentication

For this investigation, I shall be using databases from a variety of sources. The time period that I shall be investigating is between 1970-2020. This is because temperature anomalies for the period 1980-2020 are measured relative to the 1950-1980 average temperatures, the values of which are taken from the data published by NASA's Goddard Institute for Space Studies (GISS)[9]. The institute utilises satellite data to record global temperature anomalies which are much more accurate compared to those measured on the ground as they are prone to coverage bias i.e. they do not cover all regions of the planet.[10] I shall be taking data about the global carbon dioxide concentrations from the Mauna Lao Observatory of the National Oceanic and Atmospheric Organisation reported in parts per million volume (ppm)[11]. This data is accepted by the International Panel for Climate Change and is therefore safe to use.

We obtain the values of emissions from combustion of fossil fuels, emissions from the land use change, land sink and ocean sink are taken from the Global Carbon Budget 2020[5]. The data for this was obtained through compiling and averaging several other reliable research papers and databases. They are reported in units of gigaton carbon per year. We use the data from the budget to calculate the projected growth in atmospheric carbon dioxide each year and then compare it to the growth rate data from the NOAA[12]. The rise in atmospheric carbon dioxide is converted from $GtCyr^{-1}$ppm to using by multiplying it by 2.13. By assessing the correlation between the projected gain and the actual gain, we can determine whether or not human activity has caused the rise in carbon dioxide levels and similarly the rise in temperature.

RESULTS

The graphs for the global temperature anomaly vs time (in years) and carbon dioxide concentration vs time are:

[9] Change, Nasa Global Climate. "Global Surface Temperature | NASA Global Climate Change." *Climate Change: Vital Signs of the Planet*, climate.nasa.gov/vital-signs/global-temperature. Accessed 9 Apr. 2021.

[10] Chylek, Petr, et al. "Limits on Climate Sensitivity Derived from Recent Satellite and Surface Observations." *Journal of Geophysical Research*, vol. 112, no. D24, 2007. *Crossref*, doi:10.1029/2007jd008740.

[11] "Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases." *The Global Monitoring Laboratory (GML) of the National Oceanic and Atmospheric Administration*, gml.noaa.gov/ccgg/trends/data.html. Accessed 9 Apr. 2021.

[12] "---." *The Global Monitoring Laboratory (GML) of the National Oceanic and Atmospheric Administration*, gml.noaa.gov/ccgg/trends/gr.html. Accessed 9 Apr. 2021.

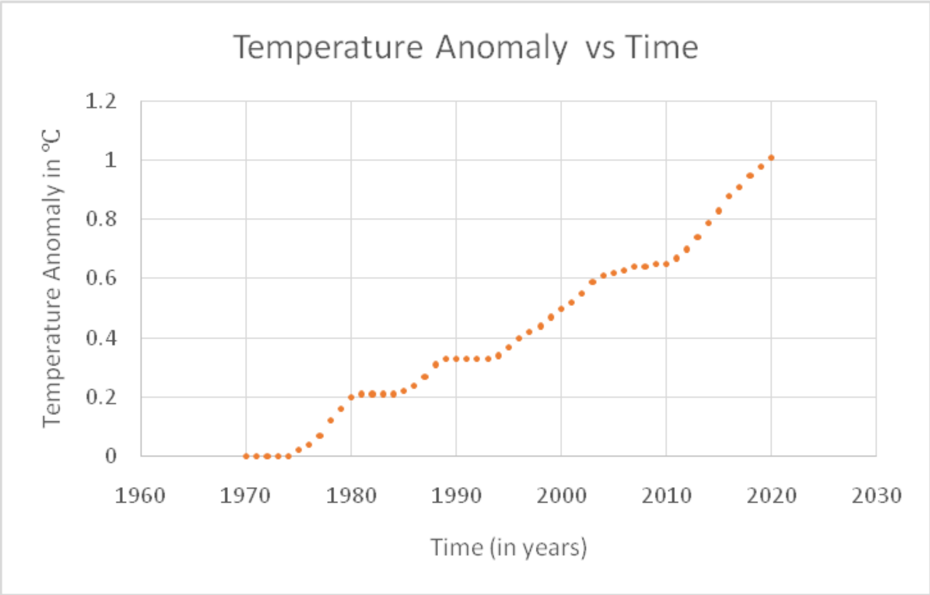

Figure 1: Temperature Anomaly vs Time.

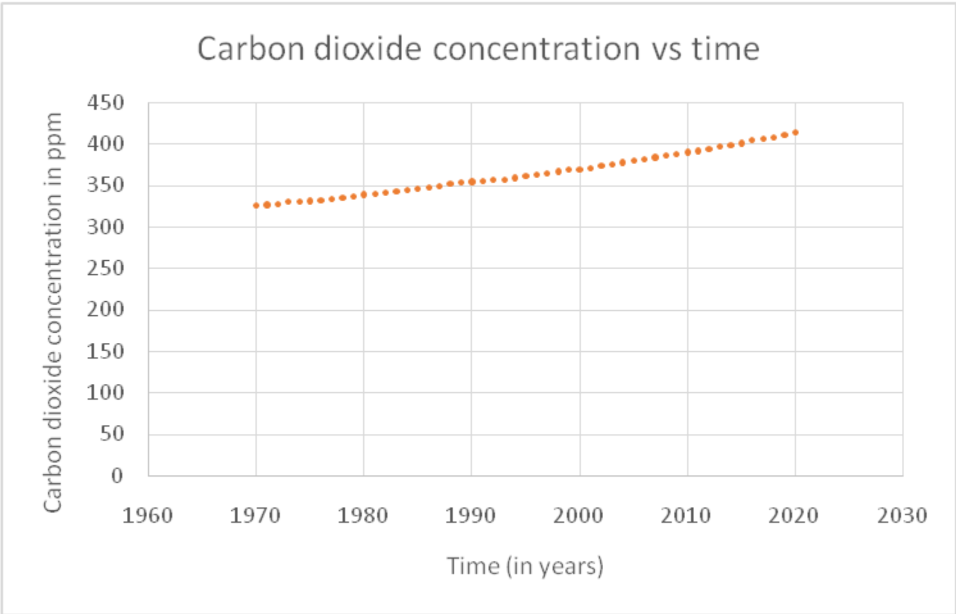

Figure 2: Carbon Dioxide Concentration in PPM vs Time.

As we can clearly see from these two graphs, both the carbon dioxide and the temperature anomalies have been rising during this period. Therefore, there appears to be some relationship between the two. To better understand this relationship, we plot both the variables against each other to get a temperature anomaly vs carbon dioxide concentration graph.

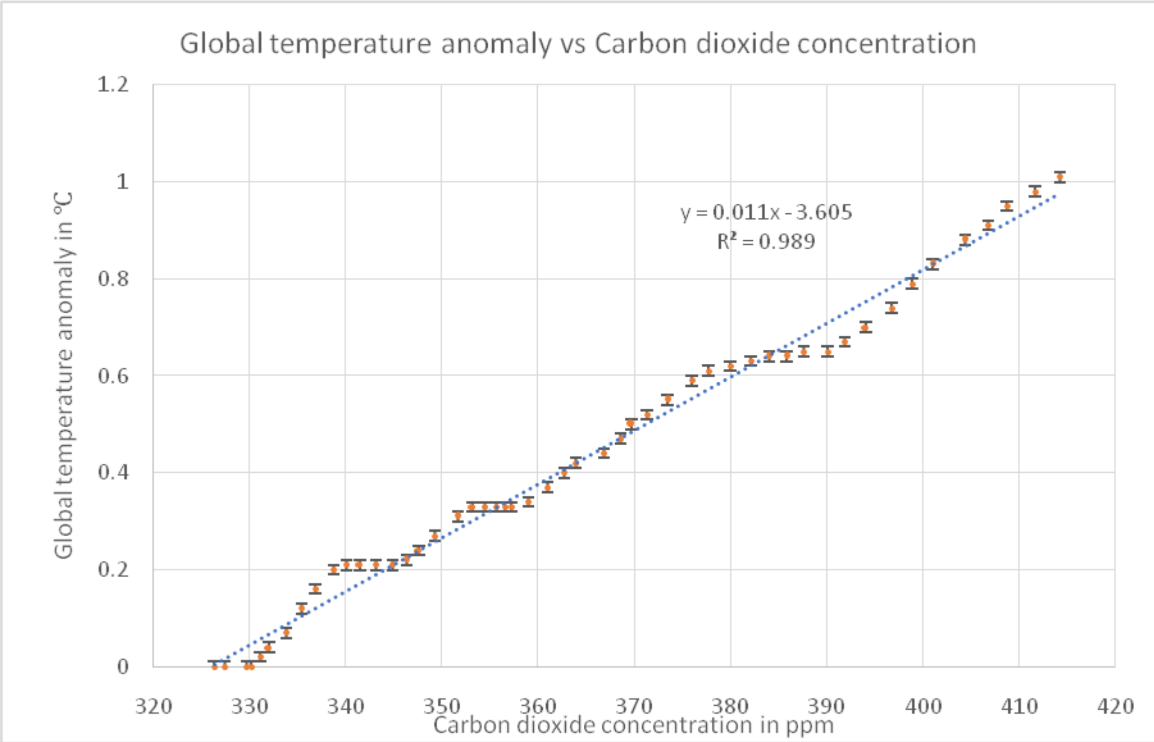

Figure 3: Temperature Anomaly vs Carbon Dioxide Concentration.

The two variables appear to have a linear relationship however, this could be because for extremely small changes in x, the logarithmic function could be approximated to be a linear function. An important point to note is that the line of best fit does not pass through any of the error bars. This is because climate in general can be interpreted to be a chaotic system and it is difficult (or even impossible) to predict exact values for temperature. The only significance for the formula is that it can point towards a general trend. The value of $R^2 = 0.9896$, is extremely close to one which indicates a strong relationship between the two variables. However, we can attempt to further improve this coefficient by fitting the curve to a logarithmic curve.

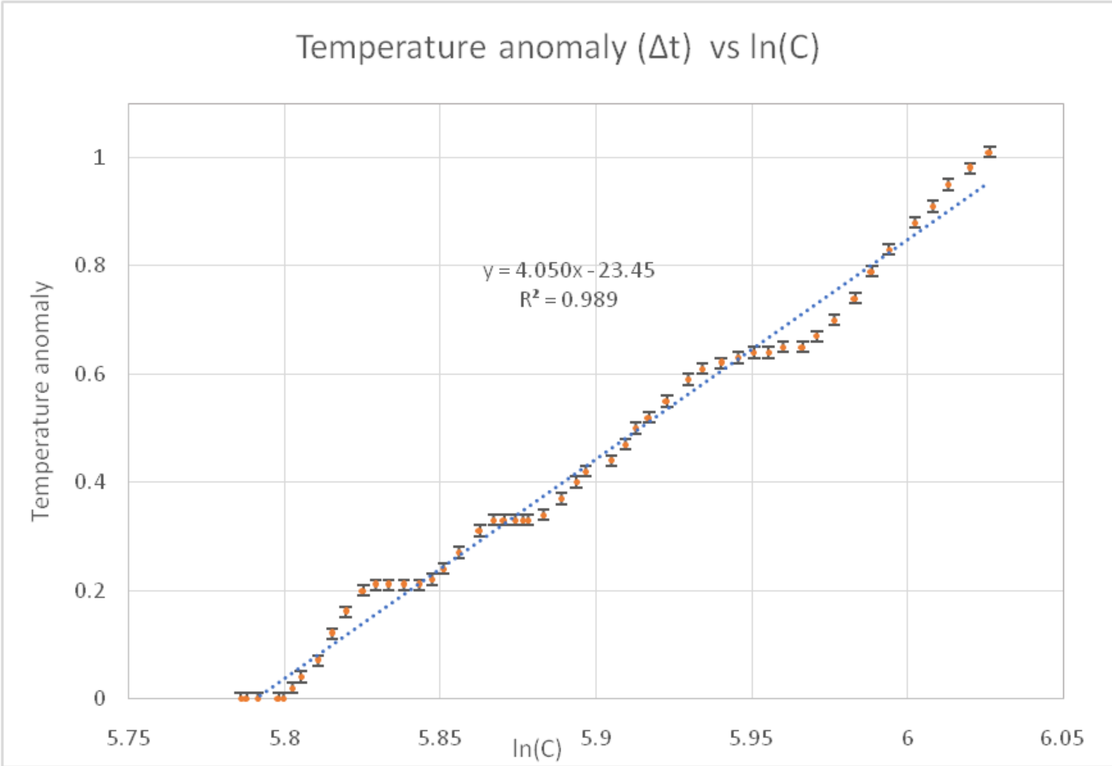

Figure 4: Δt vs ln C.

While the value of $R^2 = 0.9893$, is not greater than that in the previous linear relationship, it does not imply that the previous relationship is more accurate. This is because in the future, the change in carbon dioxide concentration will be much higher resulting in a deviation from the linear equation.

As per equation 4, the relationship between ΔT and C is given by:

$$\Delta T \propto ln\frac{C}{C_0}$$

$$\Delta T = k\, ln\frac{C}{C_0}$$

$$\Delta T = k\, ln\, C - k\, ln\, C_0$$

As per the equation in the graph $\Delta T = 4.05\, ln\, C - 23.454$. Comparing the two formulae we can say that:

$$k = 4.05\,°C$$

We can approximate the value of the equilibrium climate sensitivity by multiplying k by $ln\, 2$ as mentioned in Equation 3. This gives us:

$$S = 2.81\,°C$$

This value is extremely close to the proposed $3\,°C$ mentioned in the theory section. Using this we can also calculate the value of C_0, which is about:

$$C_0 = 327.6 \text{ ppm}$$

This is exactly the carbon dioxide concentration in the year 1972. Hence the data observed trend in temperature anomalies matches that predicted by our model.

Finally, we must analyze the global carbon budget in order to identify anthropogenic contribution to the rise in atmospheric carbon dioxide.Here we plot the projected atmospheric gain calculated as per the formula 5and the actual atmospheric gain against time.

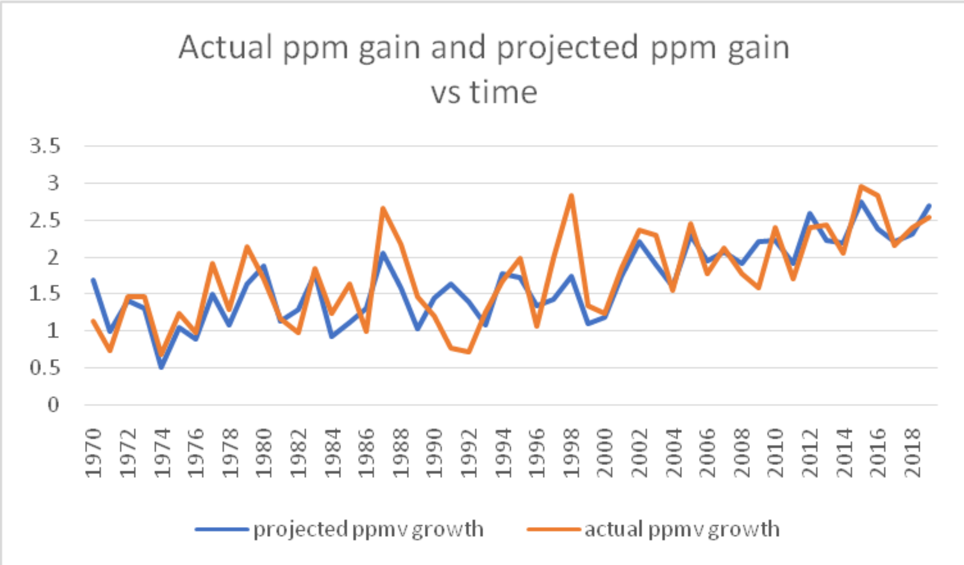

Figure 5: Actual Gain vs Projected (Anthropogenic only) Gain.

As we can see here the two graphs do have a strong correlation. The rise and falls in actual ppm gain do seem to match with our projected values. However, the values never seem to align completely. This could be due to budget imbalances which are discussed later. Quantitively, the value of R^2 for the correlation between projected and real values is about 0.7. This means that we cannot assess with complete certainty that anthropogenic sources are the sole cause for the increase in atmospheric carbon dioxide however we can say that they are a major contributing factor to the same.

We cumulatively add the values of the projected atmospheric gain to get the net anthropogenic contribution C_{human}. We now shift the values by 326.6ppm (CO_2 concentration in 1969) in order to obtain the same logarithmic relation derived before.

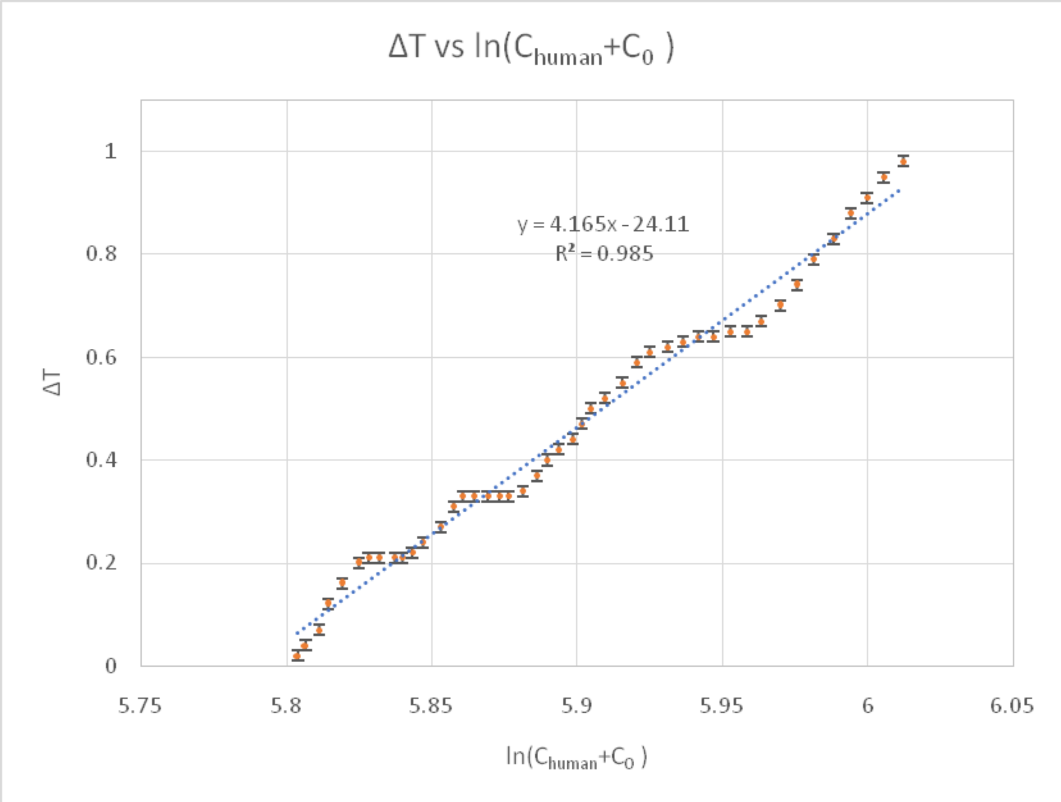

Figure 6: ΔT vs ln(C_human+C_0).

As we can see the graph obtained is extremely similar to the one obtained in Fig 4. We also obtain a climate sensitivity parameter of $S = 2.89°C$.Hence, we can say that

$$\Delta T = \frac{S}{ln\,2} ln \frac{C_0 + C_{human}}{C_0}$$

Where $S = 2.85°C$(Taking an average of the two different values of S obtained). This gives us a feedback factor $f = 2.375$ and $g = 0.58$.

UNCERTAINTIES AND ERRORS

In the research paper, there is ample scope for both random and systemic error. This is partly due to the nature of climatology itself which is chaotic in nature. However, the data about carbon dioxide concentration and temperature anomalies are the least likely to have any error as they are obtained through N.A.S.A and the N.O.A.A respectively and through the most reliable means. The uncertainty in these values is reported to their least count, $0.01°C$ and 0.1ppm.

We also notice that an error in the theoretical value for climate sensitivity ($3°C$) and its value obtained through our research ($2.85°C$) which is a 5% error. This is probably because of the range of our data as we constrict ourselves to the years 1970-2020 while most studies study data right from the start of the Industrial Revolution in 1750. Furthermore,$3°C$ is usually taken as the most probable value and slight deviations could be possible.

The same cannot be said about the carbon budget or the projected ppm growth. The data for these values have a lot of random error.As per the global carbon budget program, the uncertainty in the emissions for land use change is taken

as ±0.7 $GtCyr^{-1}$, for ocean sink as ±0.4$GtCyr^{-1}$, for land sink as ±0.9$GtCyr^{-1}$ and for fossil fuel emissions at about 5% percentage uncertainty. The uncertainty in cement carbonation is neglected as its value is too small (reported in megatons carbon per year instead of gigatons carbon per year). Taking average of all uncertainties for fossil fuel emissions brings it to an uncertainty of about ±0.12 $GtCyr^{-1}$. Using the formulae for uncertainty we can say that uncertainty in projected atmospheric growth to be about ±2.12 $GtCyr^{-1}$ or ±1.00ppm. This error is extremely high and, in some cases, even greater than 100%. The reason behind this error is that the global carbon budget takes an average of several datasets each of which have varying values. This error could be reduced by selecting one of those datasets, but this would make it susceptible to systemic errors in the process of measurement. The error in the actual atmospheric gain is ±0.1ppm which is reported to its least count[5].

The carbon budget also does not incorporate certain data which leads to a budget imbalance. For example, it does not consider the anthropogenic contribution of CO and CH_4 in the carbon budget. They assume that all carbon monoxide emissions arising from fossil fuel burning eventually convert into carbon dioxide and hence must not be double counted. The anthropogenic emission of methane is not included in E_{FOS} because fugitive emissions are not included in fuel inventories. They eventually contribute to the carbon dioxide emission however their impact is assumed to be negligible. Other anthropogenic changes in the sources of CO and CH_4 from wildfires, vegetation biomass, wetlands, ruminants, or permafrost changes are similarly assumed to have a small effect on the CO_2 growth rate.Similarly, the contribution of carbonates other than those from cement is also ignored.The missing processes include CO_2 emissions associated with the calcination of lime and limestone outside cement production. Finally a loss of sink capacity by the land due to the replacement of from vegetation types that can provide a large carbon sink per area unit (typically, forests) to others less efficient in removing CO_2 from the atmosphere (typically, croplands) is also not included.

The main reason for the imbalance in the carbon budget is most likely the errors in S_{LAND} and S_{OCEAN}. For example, underestimation of the S_{LAND} by DGVMs was reported following the eruption of Mount Pinatubo in 1991 which caused the emission of sulphur aerosols into the sky which in turn caused diffused radiation which increased photosynthetic activity thus enhancing the land sink[13]. Similar such examples have also been reported.

CONCLUSIONS

Despite the various sources of uncertainty and errors, we are able to assess the following details. Firstly, global temperature anomaly is directly proportional to the natural log of the carbon dioxide concentration divided by the initial concentration with an overall climate sensitivity estimated at about $3°C$. Second, we can say that most, if not all, of the recent rise in carbon dioxide concentration are a result of anthropogenic activity. Using this we may conclude that the net anthropogenic contribution to the gain in atmospheric carbon dioxide is the direct cause behind the rising global temperature anomalies and that there exists a logarithmic relation between the two.

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